

I. Advanced Cast Austenitic Stainless Steels for High-Temperature Components

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Objectives

- Continue and expand commercial scale-up of new CF8C-Plus cast austenitic stainless steel.
- Establish a more complete database for tensile creep and fatigue properties.
- Determine resistance to aging, fatigue, and thermal fatigue to enable redesign or prototype casting trials of stainless diesel exhaust components.

Approach

- Produce 500-lb air-melt heats of static and centrifugally cast CF8C-Plus at MetalTek International or other stainless steel foundries.
- Obtain a more complete tensile and fatigue properties database on CF8C-Plus at Caterpillar.
- Determine improvements in resistance to thermal fatigue at Caterpillar and to creep at ORNL of CF8C-Plus relative to standard CF8C steel and other typical exhaust component alloys.
- Determine the most effective new alloying additions to CF8C-Plus to maximize strength above 800°C and then down-select an alloy for commercial scale-up.

Accomplishments

- Received a 2003 R&D 100 Award for CF8C-Plus cast stainless steel.
- Selected CF8C-Plus for further commercial scale-up based on superior aging, fatigue and thermal resistance at up to 850°C compared with CN-12 or CN-12-Plus.

- Produced new commercial static and centrifugally cast smaller heats of CF8C-Plus and a larger heat for a prototype component trial for a different application.

Future Direction

- Characterize microstructural changes after selected high temperature testing or aging; complete initial aging and expand aging to new alloys and impact properties evaluation.
- Evaluate the effects of different commercial-scale casting processes on properties of CF8C-Plus steel.
- Complete alloy modification studies of CF8C-Plus to boost strength above 800°C, and commercially scale-up and test the most promising new heat.

Introduction

Advanced heavy truck diesel engines must continue to have higher fuel efficiency, as well as reduced exhaust emissions, without sacrificing durability and reliability. More demanding normal duty cycles require exhaust manifolds and turbo-charger housing materials to withstand temperatures ranging from 70°C to above 750°C. Such materials must withstand both prolonged, steady high-temperature exposure and rapid and severe thermal cycling. New emissions reduction technology and transient power excursions can push temperatures in these critical components even higher.

Current diesel exhaust components are generally made from SiMo ductile cast iron, and higher engine temperatures push such materials well beyond their current strength and corrosion limits. The first Oak Ridge National Laboratory (ORNL)/Caterpillar (CAT) cooperative research and development agreement (CRADA) produced systematic data comparing a heat-resistant cast CN12 stainless steel with SiMo cast iron for more demanding diesel exhaust component applications. It clearly identified the tensile, creep, and fatigue strength advantages of standard CN12 stainless steel at 550–700°C and above. That first CRADA project also developed new lab-scale heats of modified CN12 and modified CF8C steels with better creep strength and significantly better aging resistance and thermal fatigue resistance than standard CN12. A second ORNL/CAT CRADA project began several years ago for commercial scale-up of these new modified cast stainless steel heats, and for development of a more systematic and thorough database required by designers to redesign stainless components and qualify them for trial component production. In 2003, the initial commercial scale-up data demonstrated clear advantages of the new CF8C-Plus cast steel relative

to the other alloys for exhaust components and other applications, and this work won a 2003 R&D 100 Award. In 2004, commercial scale-up focused on the new CF8C-Plus cast stainless steel and expanded to include more commercial heats, several different casting processes (static sand-casting, centrifugal casting), and alloying modifications to increase maximum strength at the highest temperatures.

Approach

Two commercial stainless steel foundries initially produced 500-lb heats of CN12-Plus and CF8C-Plus steels for testing and evaluation compared with similar standard steels. One of those commercial foundries produced additional new static-cast and centrifugally-cast heats of CF8C-Plus. Caterpillar Technical Center obtained tensile, fatigue, and thermal-fatigue data on these new heats of CF8C-Plus steel, while ORNL obtained initial creep-rupture data and aged specimens for various times at 700–850°C. ORNL also cast a new set of lab-scale heats to explore the effects of adding Al, B, Cu, and W to CF8C-Plus to maximize strength and creep resistance at 800–850°C. Results of the testing will be used to expand commercial scale-up of CF8C-Plus and then to down-select a heat of the new modified CF8C-Plus for commercial scale-up.

Technical Progress

Tensile, fatigue, and thermal fatigue testing on the initial commercial heats of CF8C-Plus and CN-12 Plus were completed earlier at Caterpillar. Tensile data clearly showed CF8C-Plus to be as strong as standard CN12 and CN-12-Plus cast steels and much more ductile, with no additional heat treatment required after casting. CF8C Plus has an “engineered microstructure,” which includes a very

stable austenite parent matrix phase that is free of the δ -ferrite typically found in standard cast CF8C. The creep strength of CF8C-Plus at high temperatures comes from nano-scale dispersions of NbC precipitates that form and remain stable and are much finer than those found in standard CF8C steel. Because CF8C-Plus has no δ -ferrite, it is also free of σ -phase relative to standard CF8C during aging or creep at 650–850°C.

Creep rupture stress versus rupture life, expressed as the Larson Miller Parameter (LMP), for standard CF8C and CF8C-Plus tested at 750–850°C is plotted in Figure 1, together with data from high-SiMo and Ni-resist cast irons tested at lower temperatures. Clearly the CF8C-Plus cast stainless steel has about twice the creep strength of standard CF8C steel, and both are much stronger than either high-SiMo or Ni-resist cast irons. Figure 2 shows the significant advantage the CF8C-Plus alloy has in low-cycle fatigue resistance compared with standard CN-12 steel at 800°C, which was a factor in choosing CF8C-Plus for further commercial scale-up for diesel exhaust component applications. The fatigue behavior of cast CF8C-Plus with a very coarse as-cast grain structure also compares well with wrought-type 348 stainless steel (similar alloy composition) with a much finer grain size. CF8C-Plus was deliberately designed to have a combination of good strength and ductility at both higher and lower temperatures, in order to achieve its best fatigue and thermal fatigue resistance. Thermal-mechanical fatigue (TMF) testing of these initial commercial heats was completed this year, together with aging of various specimens. There was a significant advantage for CF8C-Plus relative to CN-12 or high-SiMo cast iron in TMF testing to 760°C or higher, and data will be shown next quarter.

Additional lab heats of CF8C-Plus were cast at ORNL to define the effects of other minor alloying additions, including B, Al, Cu and W additions, and establish their limits for commercial heats. Creep-rupture test screening at 750–850°C showed that copper and tungsten were most effective at improving creep resistance, as shown for creep testing at 750°C in Figure 3. Based on these data, a modified CF8C-Plus with copper and tungsten additions was selected for the next step of commercial scale-up and testing.

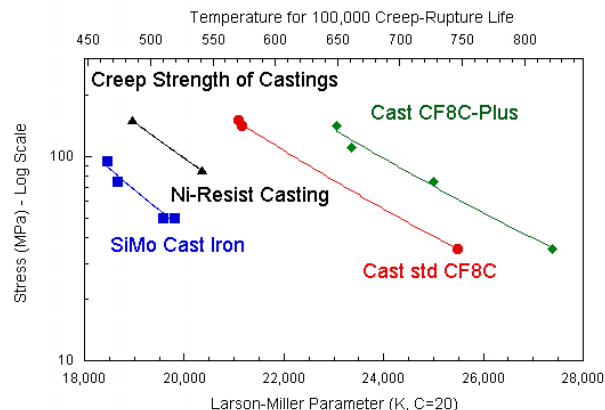


Figure 1. Larson Miller parameter plot of creep rupture stress for high-SiMo and Ni-resist cast irons, standard CF8C, and the new CF8C-Plus cast stainless steels tested in air at various temperatures.

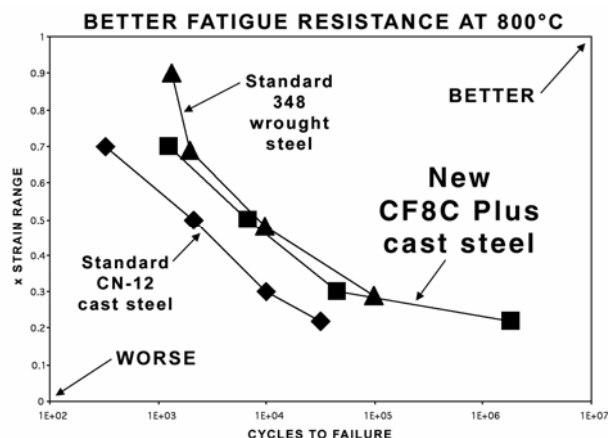


Figure 2. Isothermal strain-controlled fatigue data versus cycles to failure in air at 800°C, for commercial scale-up heats of standard CN-12, CN-12-Plus, and CF8C-Plus cast stainless steels.

Finally, this year, MetalTek International produced additional static sand-cast and centrifugally-cast heats of CF8C-Plus for testing at Caterpillar and ORNL. That testing began this year and will be completed next year. MetalTek International has also produced several heats of a new CF8C-Plus with copper and tungsten additions, selected from the ORNL lab-scale heat data on alloy modifications, and testing will begin next year.

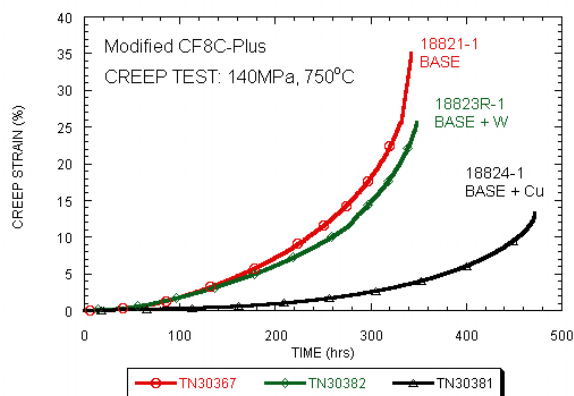


Figure 3. Creep-rupture testing in air at 750°C and 140 MPa of new ORNL lab heats of baseline CF8C-Plus steel and the same steel with additions of copper or tungsten.

Conclusions

ORNL and Caterpillar have chosen CF8C-Plus cast stainless steel as the focus for further scale-up and development, based on the initial commercial scale-up results of CN-12-Plus and CF8C-Plus. The development of CF8C-Plus was recognized with a 2003 R&D100 Award. Several static-cast and centrifugally-cast heats of CF8C-Plus were produced by MetalTek International for further testing for diesel engine exhaust component applications and other high-temperature structural component applications. Another set of ORNL lab-scale heats of CF8C-Plus were made to test the effects of minor alloying additions on improved creep resistance above 800°C, and copper and tungsten additions were found to be most effective. New commercial heats of CF8C-Plus and CF8C-Plus with copper and tungsten were produced by MetalTek this year and will be tested next year.

Publications/Presentations

P. J. Maziasz and M. J. Pollard, "High-Temperature Cast Stainless Steel," *Advanced Materials & Processes* (ASM-International), **161**, 57-59 (October 2003).

P. J. Maziasz, "Development of CF8C-Plus: A New Cast Austenitic Stainless Steel with Improved Heat-Resistance and Performance above 650°C," invited presentation at ASM Peoria Chapter Meeting, April 5, 2004.

M. J. Pollard, P. J. Maziasz, and J. P. Shingledecker, "Development of Low-Cost Cast Austenitic Stainless Steel for Diesel Engine and Gas Turbine Components," Project Review of DOE Programs at Caterpillar, April 2004.

P. J. Maziasz, J. P. Shingledecker, N. D. Evans and M. J. Pollard, "Advanced Cast Austenitic Stainless Steels for Diesel Engine and Gas Turbine Components," presentation at DOE FreedomCAR and Vehicle Technologies Program Review at ORNL, June 15, 2004.

Special Recognitions/Awards/Patents

ORNL and Caterpillar received a 2003 R&D 100 Award for "CF8C-Plus Cast Stainless Steel for High-Temperature Performance," presented at the R&D Awards Banquet in Chicago on October 16, 2003.

P. J. Maziasz, T. McGreevy, M. J. Pollard, C. W. Siebenaler, and R.W. Swindeman, "Heat and Corrosion Resistant Cast CN-12 Type Stainless Steels with Improved High Temperature Strength and Ductility," U.S. patent application 2003/0084967, filed July 15, 2002..

P. J. Maziasz, T. McGreevy, M. J. Pollard, C. W. Siebenaler, and R.W. Swindeman, "Heat and Corrosion Resistant Cast CF8C Stainless Steels with Improved High Temperature Strength and Ductility," U.S. patent application 2003/0056860, filed July 15, 2002.